



Tunable, Narrowband Filter for LWIR Hyperspectral Imaging

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Technical Monitor: Mr. Ray Haren

Air Force Research Laboratory

Sensors Directorate

Targeting Branch

Wright-Patterson Air Force Base

Dayton, OH

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JAWS Symposium
June 16, 1999*



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Program Objectives

- ☐ Fabricate a prototype tunable filter based on liquid crystal-filled Fabry-Perot etalon (LCE).
- ☐ Enable voltage-controlled, tunable, narrow-band filtering at LWIR wavelengths
- ☐ Bandpass tunable at 60 Hz frame rates
- ☐ Enable rapid scene characterization for camouflaged target, or chemical identification
- ☐ Ability to build up Hyperspectral data cube with scanning software



Digital IR Microcam Camera Set-up



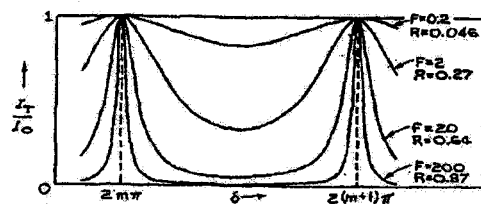
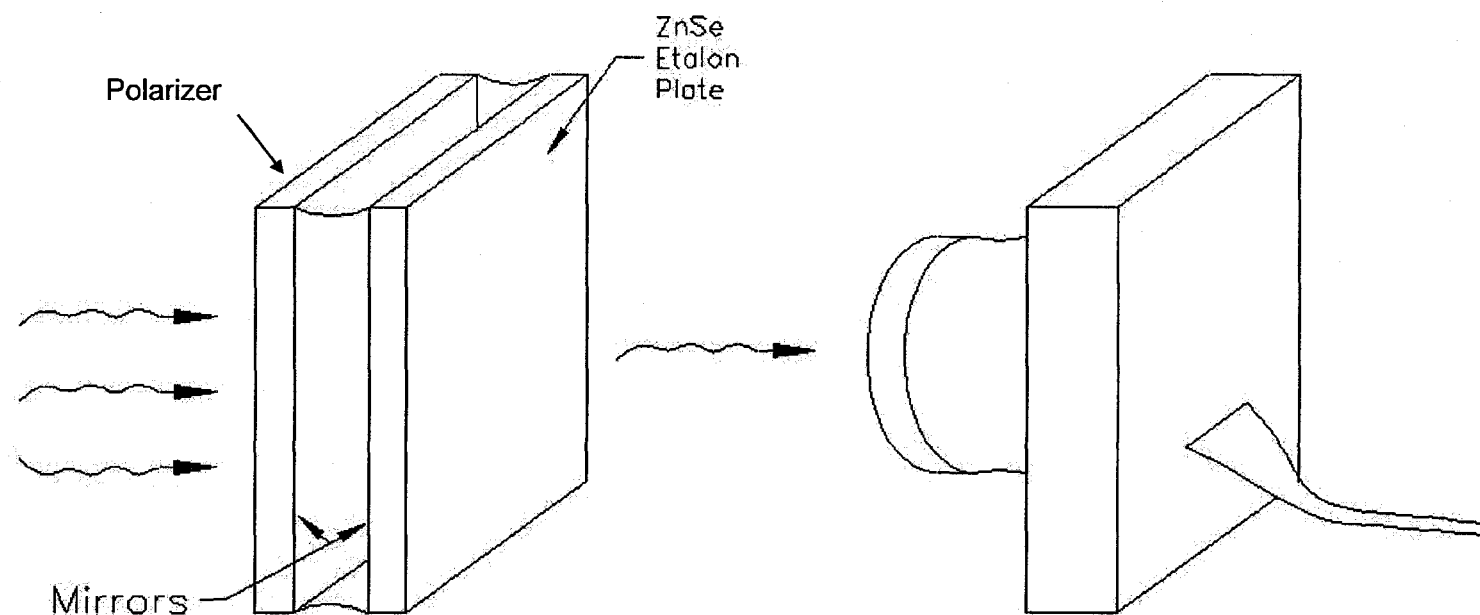
- ☐ Digital 8-12 micron IR Microcam Camera mated with a IR filter wheel holder.
- ☐ Using existing F1, 33°x25°field of view lens

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Hyperspectral Liquid Crystal Etalon

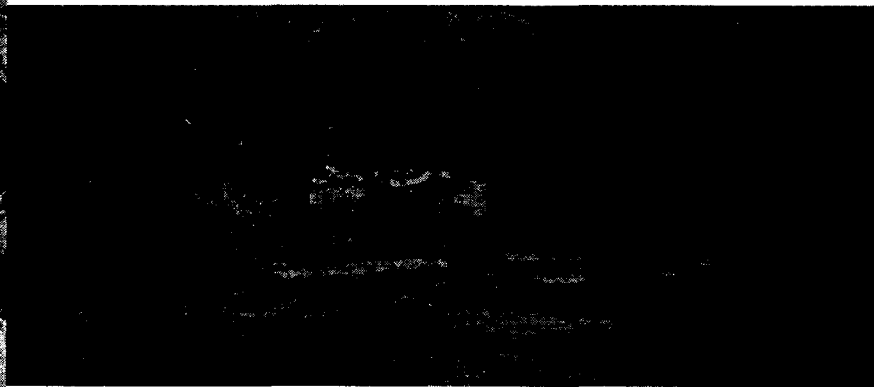
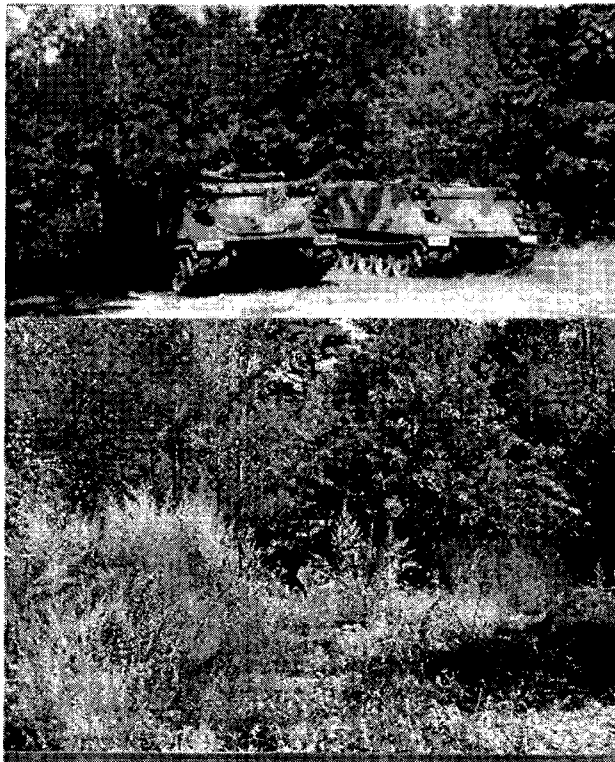


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Potential Applications: Camouflage Penetration

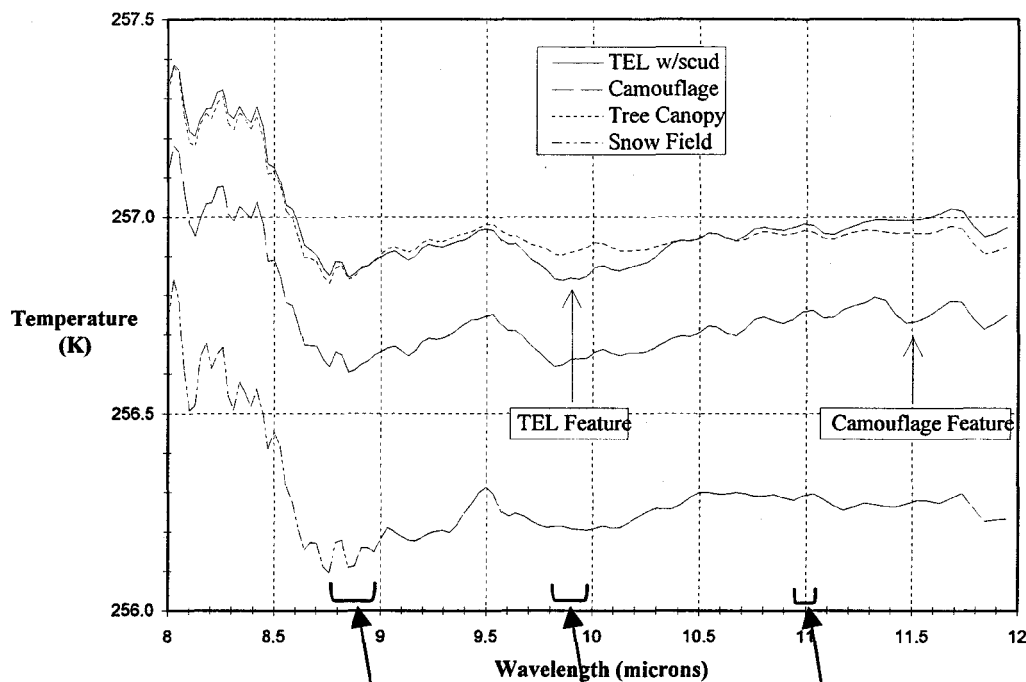


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LWIR Comparison of Target & Background



Paint		Camo
U.S.	Foreign	Clutter
9.1-9.3	9.7-9.9	9.4-9.6
FWHM: 0.2 to 0.4 μm		
From J. Cedarquist		

Phase I filter
passbands

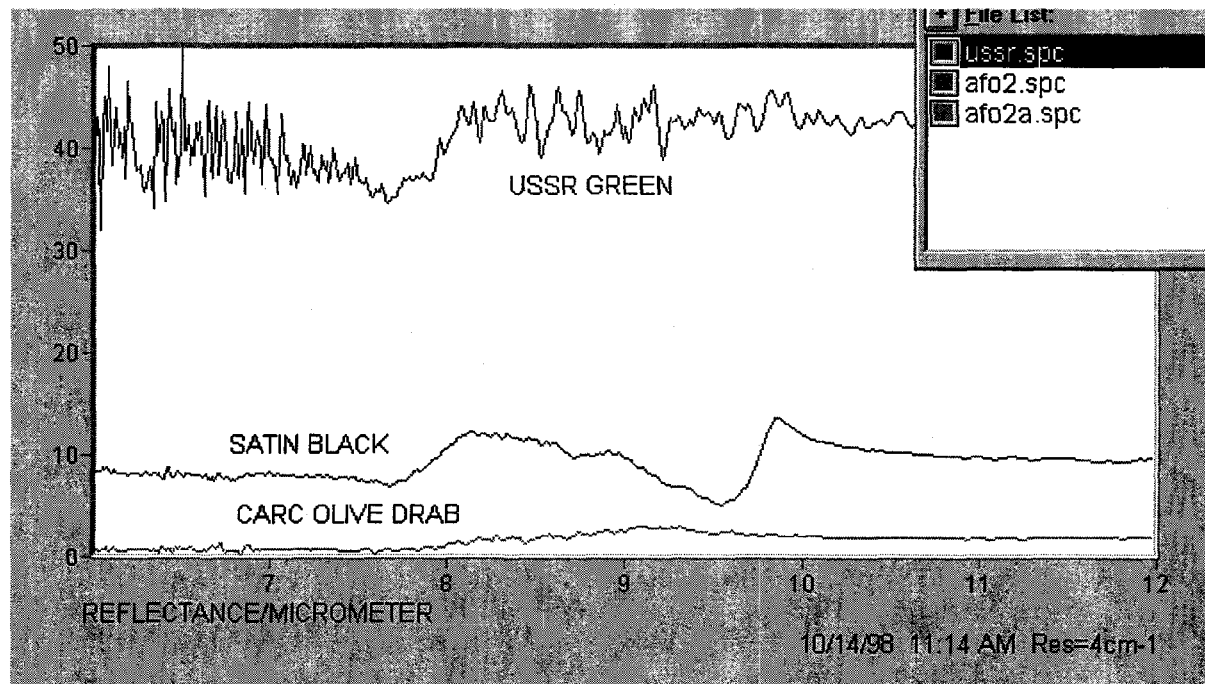
ERIM data shows typical paint, tree canopy and camouflage spectra in the 8 to 12 μm range. We selected filters to capture data around the SCUD spectral feature. This was compared to data from pictures on either side of the feature

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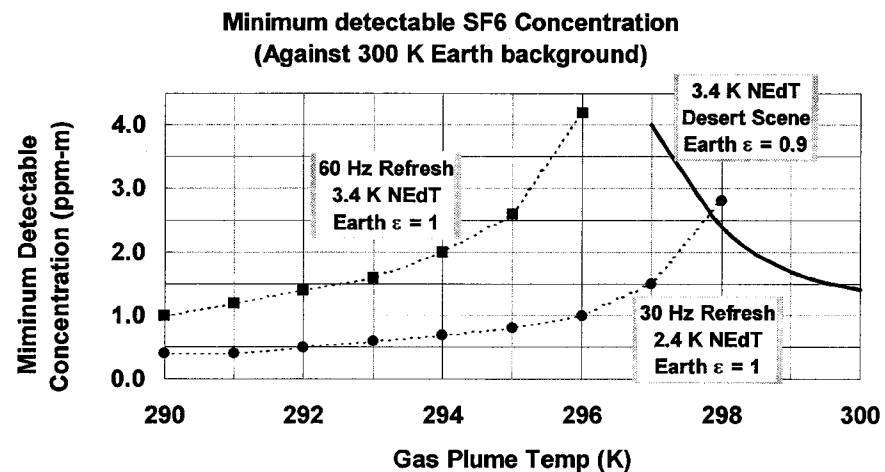
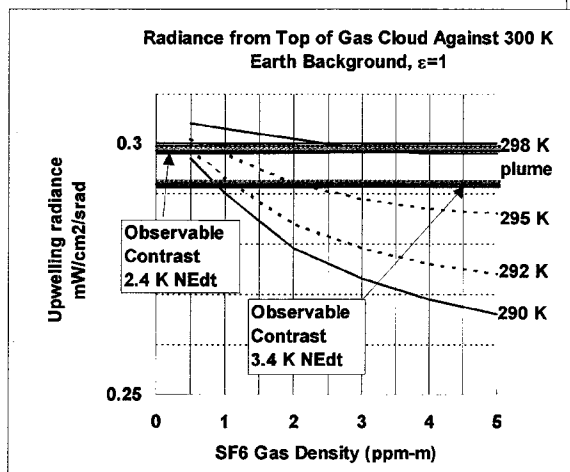
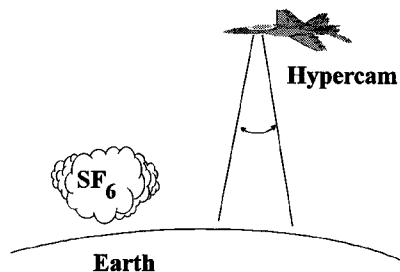
LWIR Comparison of Camouflage Paints



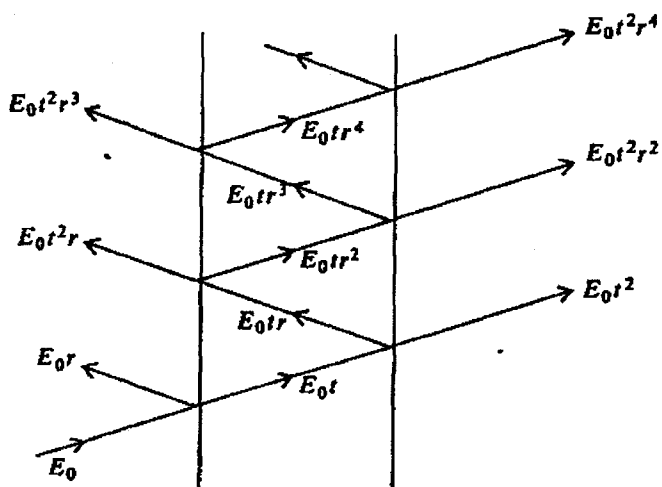
FTIR spectrum of camouflage paints. Our measured data of several paint samples shows that the spectral features are actually much larger than those provided by ERIM



Potential Applications: Standoff Plume Detection



Fabry-Perot Etalon



Phase difference between two successive rays is the optical path plus the phase shift from two reflections

$$Tx = \left[1 - \frac{A}{1-R} \right]^2 \cdot \left[\frac{1}{1 + \left[\frac{4 \cdot R}{(1-R)^2} \right] \cdot \sin^2 \left(\frac{2 \cdot \pi \cdot n(v) \cdot d \cdot \cos(\theta)}{\lambda_0} + \delta(\lambda) \right)^2} \right]$$

Where:

A = mirror absorption

R = mirror reflectivity

$n(v)$ = LC index of refraction, and is a function of applied voltage

d = LC thickness

λ_0 = free space wavelength of incident light

$\delta(\lambda)$ = phase shift on reflection

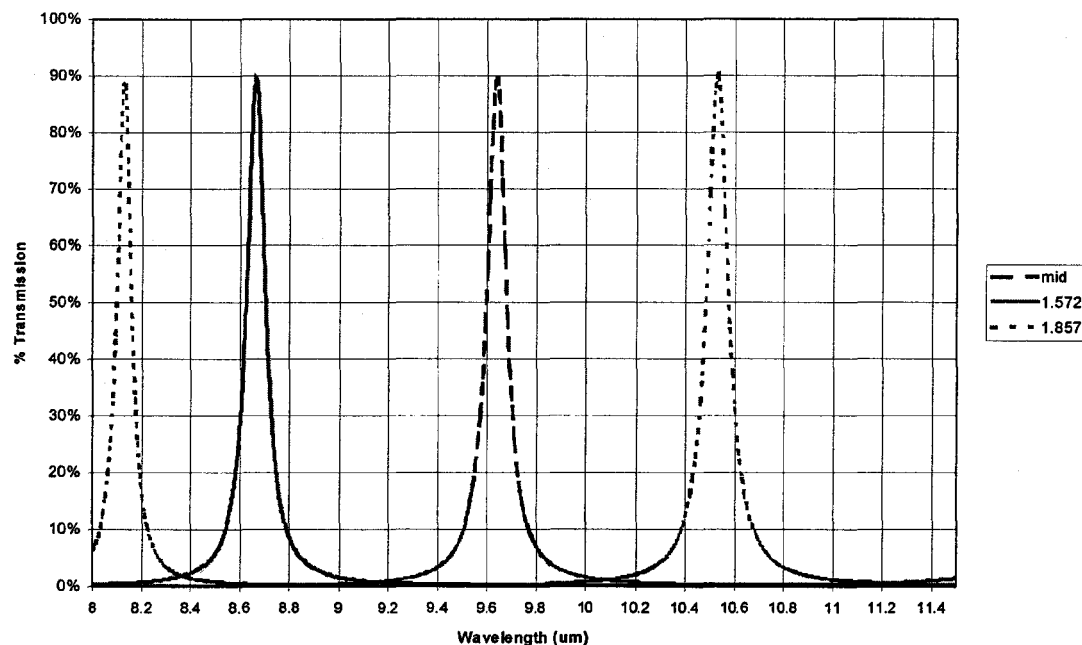
θ = incident angle of rays entering LC



LCE Transmission Model



LCE Transmission with 11.25 μm layer



**Three runs at $n(v) =$
1.572, mid, and 1.857**

**Transmission tuning range:
8.7 to 10.55 μm**

Bandpass: 0.1 μm FWHM

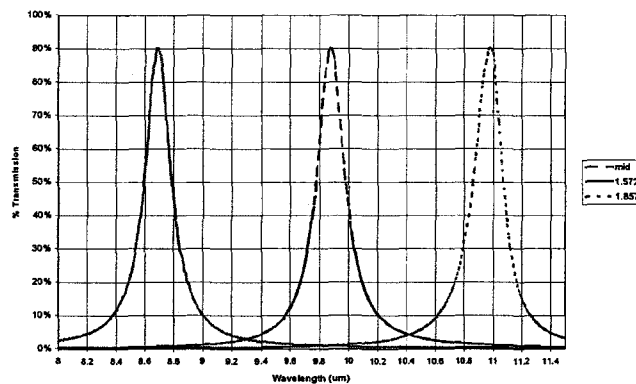
Free Spectral Range: 2.4 μm



Changing Gap Changes Interference Order, Bandpass

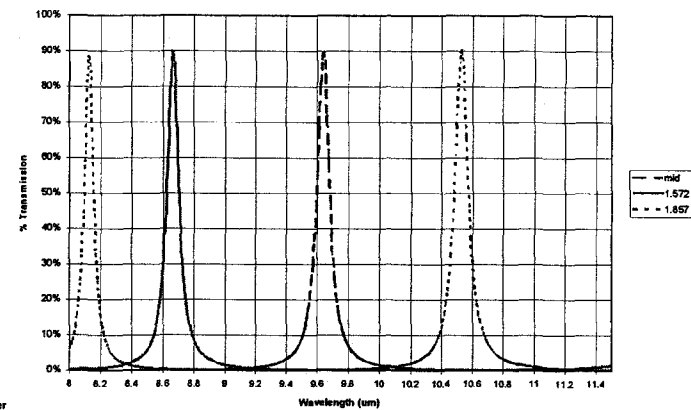


LCE Transmission with 5.75 μm layer



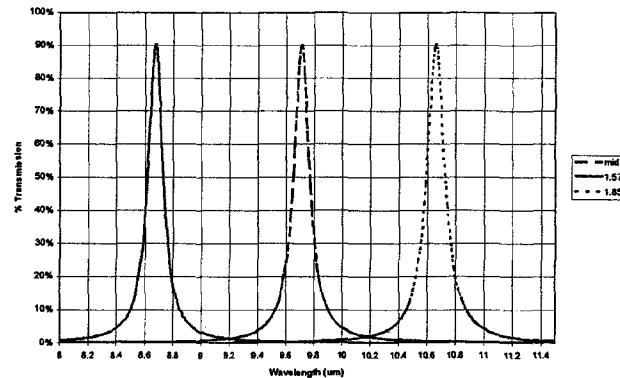
**5.75 μm gap, 3rd order
0.22 μm bandpass**

LCE Transmission with 11.25 μm layer



**11.25 μm gap, 5th order
0.10 μm bandpass**

LCE Transmission with 8.5 μm layer



**8.5 μm gap, 4th order
0.13 μm bandpass**

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Reflection phase is critical to LCE gap size

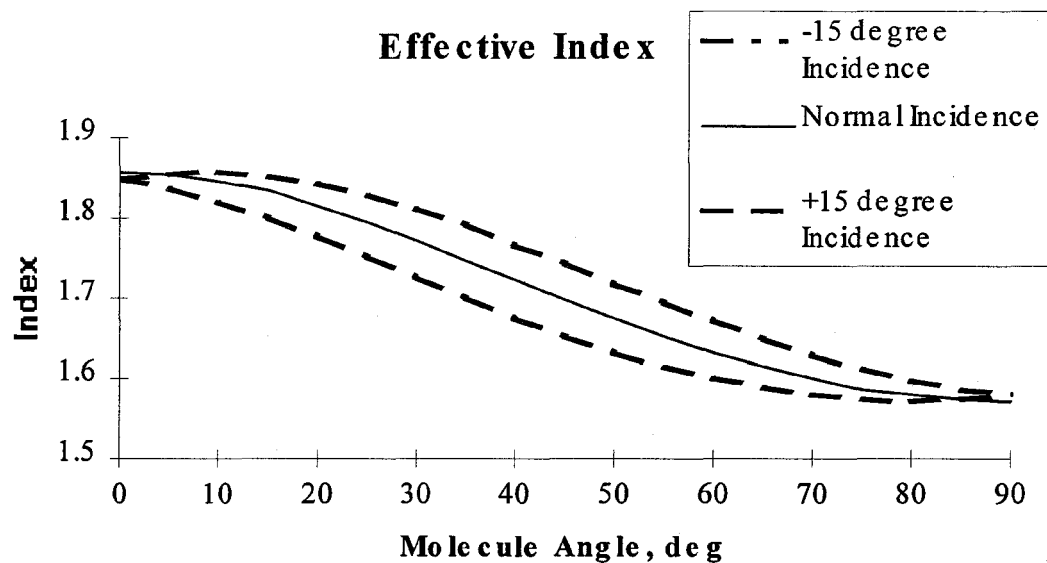


Wavelength (um)	Phase shift (deg)	Wavelength (um)	Phase shift (deg)
8	150.8551	9.6	176.7255
8.1	153.7042	9.7	177.7442
8.2	156.2353	9.8	178.7416
8.3	158.5013	9.9	179.7212
8.4	160.5476	10	180.6861
8.5	162.4122	10.1	181.6394
8.6	164.1258	10.2	182.5835
8.7	165.7132	10.3	183.5211
8.8	167.1947	10.4	184.4543
8.9	168.5868	10.5	185.3855
9	169.903	10.6	186.3166
9.1	171.1545	10.7	187.2498
9.2	172.3507	10.8	188.1869
9.3	173.4996	10.9	189.1298
9.4	174.608	11	190.0805
9.5	175.6816		

***Calculated from thin film
model of dielectric mirror.
Phase shift is a function of
wavelength.***



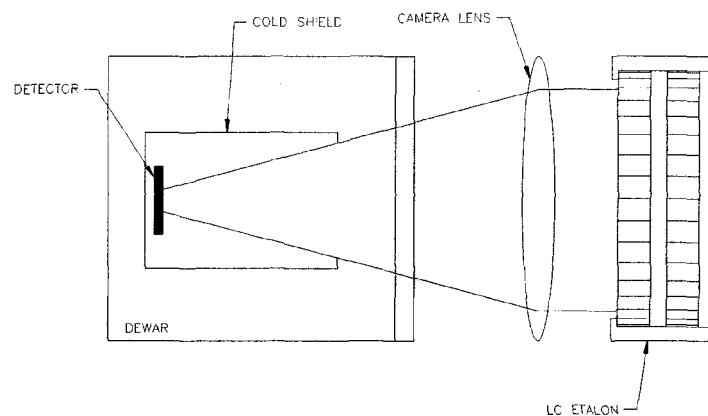
Apparent Index Vs. Incidence Angle



Plot of effective index of refraction of the LC, as the applied voltage causes the molecules to tilt. Note that the effective index also depends on the angle in which the light ray traverses the crystal.

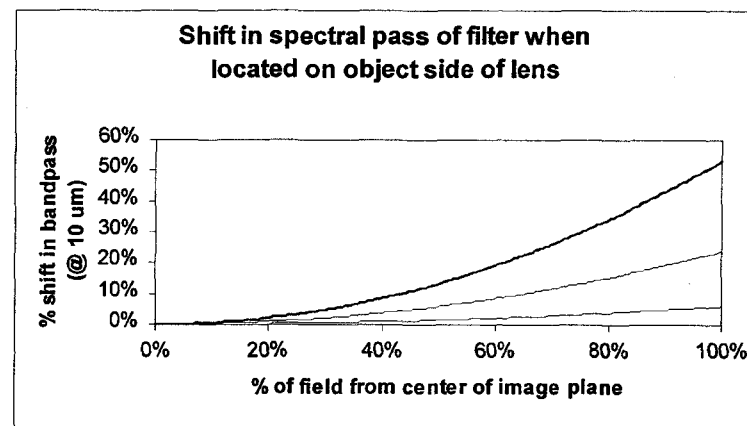


System Issues

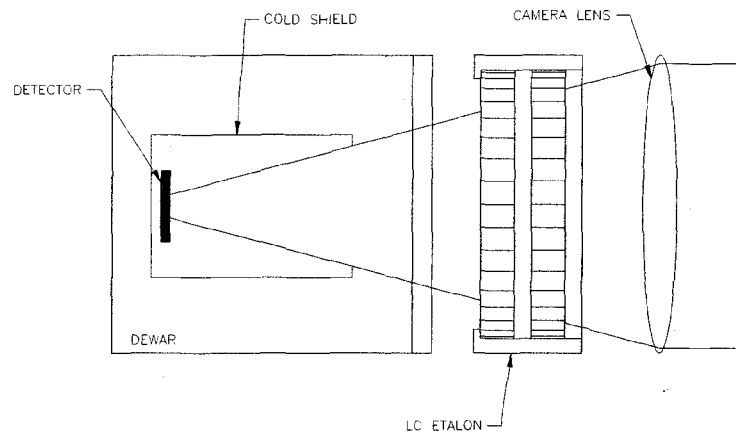


Filter before the lens

Bandpass peak shifts radial across FPA

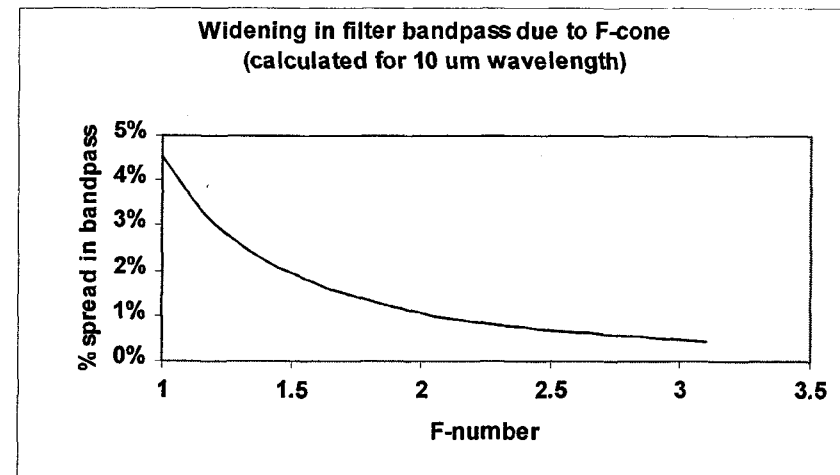


System Issues



Filter after the lens

Bandpass widens depending on F#

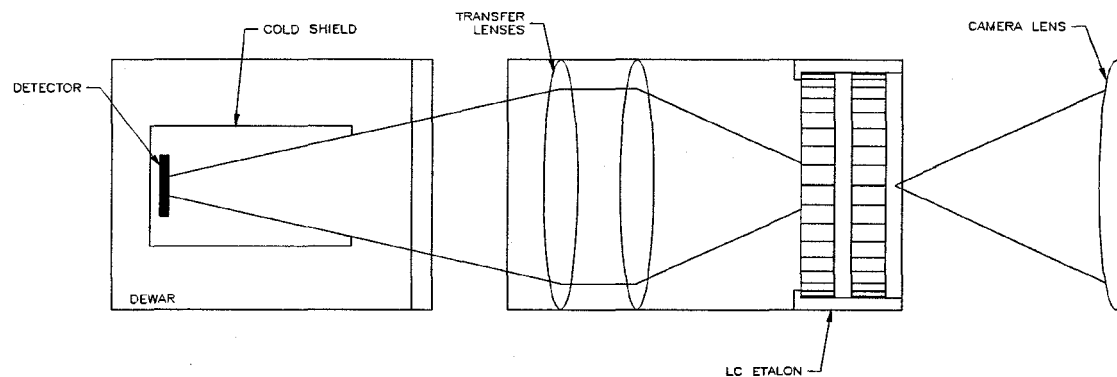


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System Design: Relay Reduces Stray Light



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LCE/camera System Model

MS DOS Prompt - DEARRAY									
Auto									
Receiver Parameters									
300		Number of Pixels							
2.5	cm	Receiver aperture							
25	deg	Total FOV	264		SI/ST	(μ Watt/cm ² / K)			
.9		Xmission thru rcvr optics	1.27		f/#				
.9		Xmission through filter	3.18	cm	Focal Length				
8	μ m	Filter Cut-on Wavelength	3.49	in	Pixel Image at 200 feet				
14	μ m	Detector Cut-off	1.45	mmrad	Pixel Field of view				
System Parameters									
301	K	Temperature of target	.001		Probability of false alarm				
300	K	Temperature of background	.999		Probability of Detection				
2	/Km	Atmospheric ext. coeff.							
.3		Target Emittance	DEARRAY		System Name				
Detector Parameters									
60	hz	Frame Rate	2		Read-out Noise Figure				
50	%	Fill Factor	1E-7	W/K	Thermal Conductance				
80	%	Absorptance	46.25	μ m	Detector Side Dimension				
90	%	Xmission thru Window	.035	K	NETD				
For Pfa = 0.001, Required TNR = 3.09 SNR at 0 ft Range = 8.57 For Pd = 0.999, Required SNR = 6.18 SNR at 200 ft Range = 7.59 Min DEL Temp to detect @ 200 ft = 0.81 K Maximum Detection Range = 537 ft (R)eceiver (S)ystem (D)etector (Q)uit									

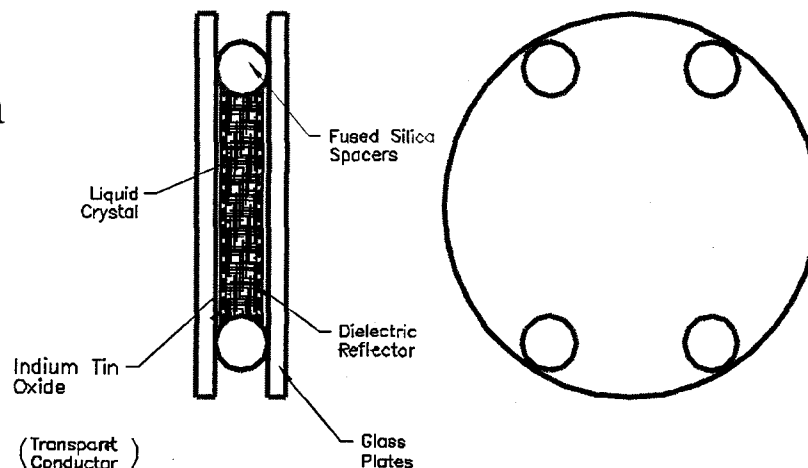
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Liquid Crystal Etalon

- Physical Diameter: 50.8 mm
- Clear Aperture: 45 mm
- Refractive Index: 1.57-1.86 μm
- Free Spectral Range: 2.4 μm
- Gap (LC thickness): 8.5 μm
- Tuning range: 8.7 to 10.7 μm
- Bandpass FWHM: 0.13 μm
- Resolution: 1.3%
- Finesse ≥ 20
- Mirror material: ZnSe



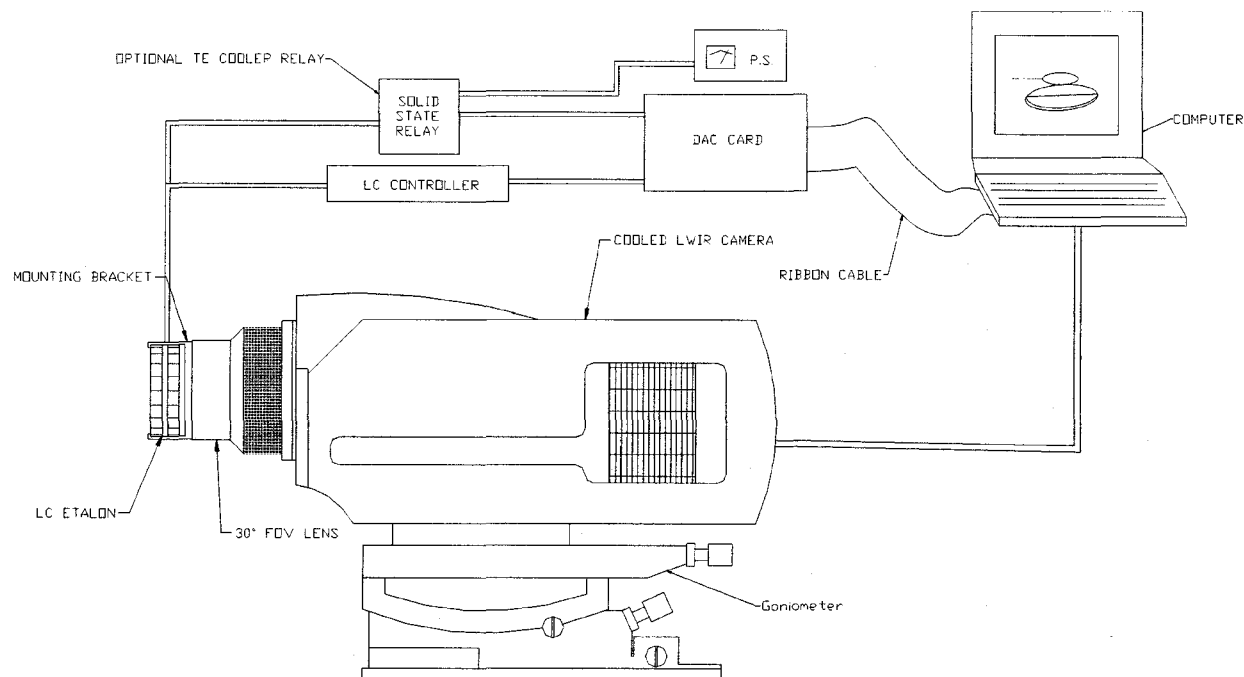
Task 2: IR Camera Trade-off



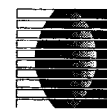
- *Model calculates MRTD at 200 ft. based on LCE properties and camera f#, FOV, spectral band pass, etc.*
- *Must determine system limitations with best available cameras*
- *Cameras to be considered: QWIP, HgCdTe, Microbolometer, BST*



LCE & Camera Test set-up



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Conclusions

- ☐ ***Rapidly tunable narrow band LWIR filter***
- ☐ ***Convert LWIR camera to
Hyperspectral imager***
- ☐ ***Create Hyper-data
cube with scanning software***
- ☐ ***Applications include chemical and
target identification***
- ☐ ***Suitable for terrestrial and
space born applications***
- ☐ ***Prototypes available in 2000***

